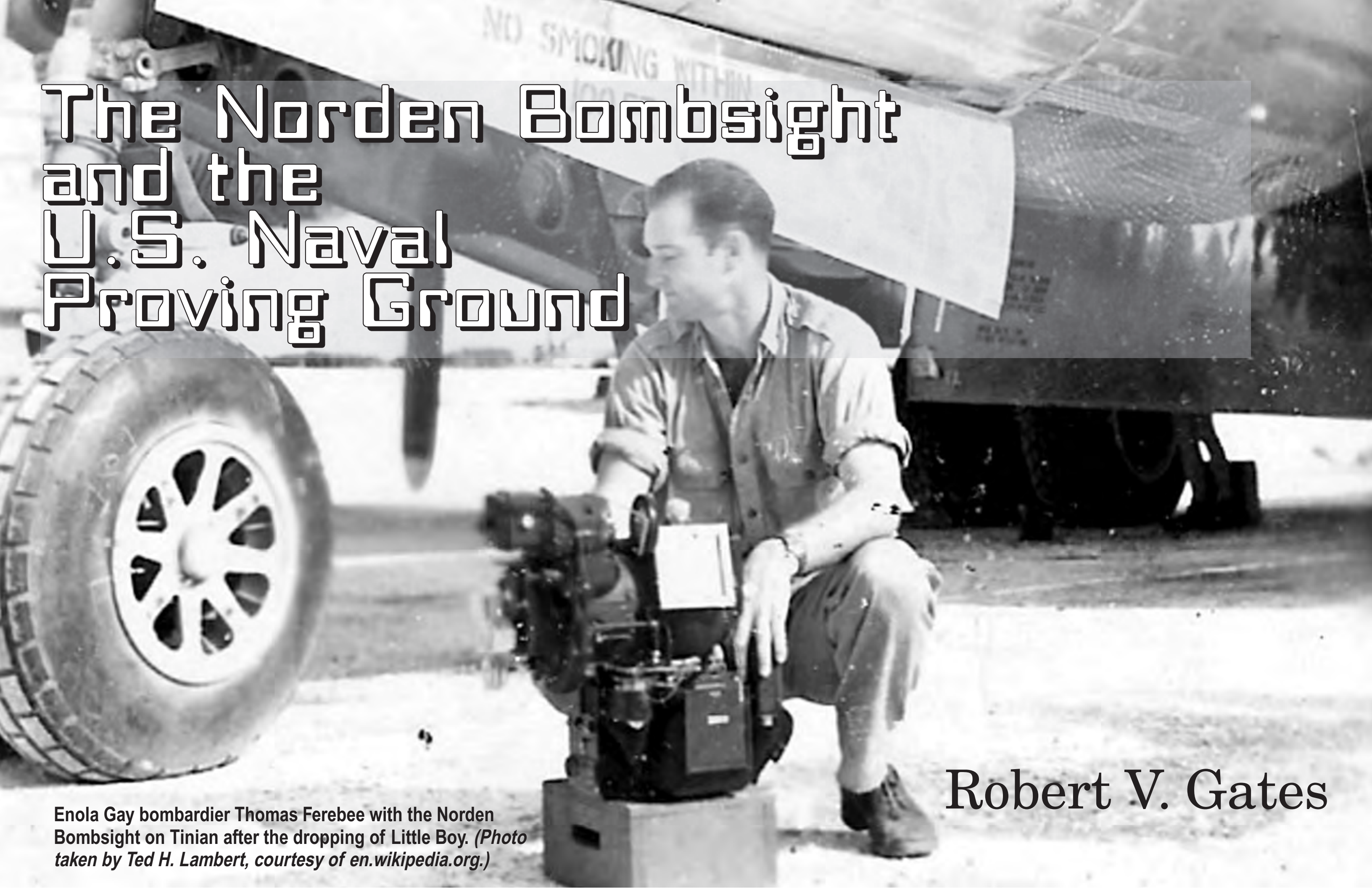
AIR POWER *History*

SUMMER 2020 - Volume 67, Number 2
WWW.AFHISTORY.ORG

know the past
.....*Shape the Future*

The Norden Bombsight and the U.S. Naval Proving Ground

Robert V. Gates



Enola Gay bombardier Thomas Ferebee with the Norden Bombsight on Tinian after the dropping of Little Boy. ***(Photo taken by Ted H. Lambert, courtesy of en.wikipedia.org.)***

The Norden Bombsight and the Army Air Force are forever linked in public memory. Less well remembered, however, are that the bombsight was developed by Carl Norden for the U.S. Navy and the role that the Navy Proving Ground (Dahlgren, Virginia) played in its development and utilization in World War II.

While there were visionaries who saw possibilities for the offensive use of aircraft during war, many senior officers and military theorists thought of aircraft, when they thought of them at all, in scout or reconnaissance roles. During World War I, others began to think of using aircraft as bombers and bombing missions were attempted from low altitudes by aircraft carrying a small load of bombs. Bombs were dropped by the pilot or observer without the benefit of an aiming device, or bombsight. Needless to say, bombing was hit or miss—mostly miss. It was constrained by the state of technology—in aircraft, bombs, and bombsights—as well as operational issues such as poor navigation.

As the development of specialized bombing aircraft increased, the need for accuracy also grew. An approach to solving the bombing problem led to the development of bombsights by the air forces of all combatants.

Early Developments

The bombing problem is more easily stated than solved. It is, essentially, the calculation of the point in space where bombs should be dropped in order to hit the target in the presence of a variety of external forces, such as gravity, wind, and bomb ballistics. Aircraft altitude, speed, and angular orientation also have a significant effect on the bombing solution and, consequently, accuracy.

The problem was generally simplified by requiring the pilot to maintain a predetermined speed and altitude and to maintain a constant attitude in pitch, yaw, and roll. Lower bombing altitudes mitigated aerodynamic (bomb ballistics) effects on accuracy. Early bombsights required the pilot to fly his bombing run either directly upwind or downwind.

One of the earliest bombsight developments was by Lt. Riley E. Scott (U.S. Army Coast Artillery) in 1911. He developed a hand-held device that was used while lying prone on the wing of the aircraft. It used aircraft airspeed and altitude as inputs based on a table of settings that he developed by extensive testing. He demonstrated the bombsight by dropping two eighteen-pound bombs within ten feet of a four foot by five foot target from an altitude of 400 feet.

The British began experimenting with bombsights in 1916. The most promising, developed by Lt. Cdr. Harry E. Wimperis of the Royal Naval Service's Imperial College of Science, was described as "little more than a board fitted with a bubble level and two adjustable rifle sights." (next page) The pilot would fly perpendicular to the bombing run in order to

The Drift Bombsight. ***(USAF photo.)***

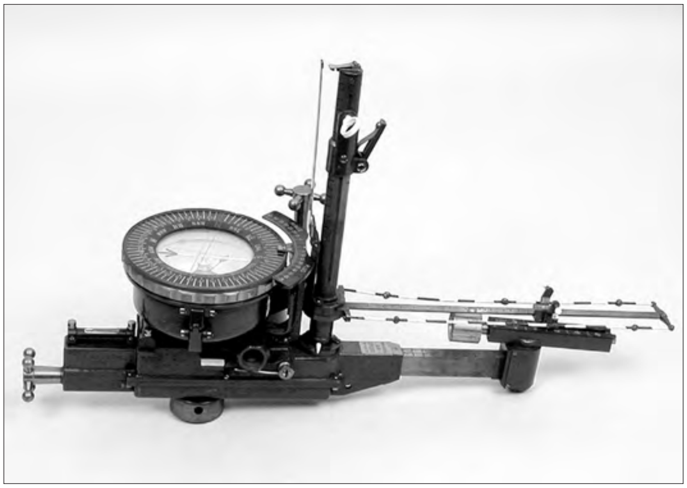
measure wind speed which would be used to set ground speed in the bombsight. Predetermined bombing tables and levers to adjust for altitude and speed and bomb ballistics were used to achieve an accuracy of "hundreds of feet." The front and rear sights on the bombsight were used to time the drop. A primary source of inaccuracy was the random pitch and roll of the aircraft during the bombing run. This sight was only effective at low altitudes, e.g., 500 to 2000 feet.

The next evolution, late in World War I, was the vector bombsight. As the name implies, it used vector mathematics to account for wind direction and speed. The observer (in a multi-place aircraft) would use adjustments of the bombsight to measure wind speed and direction and give the pilot course corrections to cancel out the drift. Originally, these corrections were conveyed to the pilot by hand signals or pulling straps attached to his shoulders. This didn't work in larger aircraft and a "pilot direction indicator"—an electrically-driven pointer—was developed after the war. The bombardier then used the front and rear sights to time the drop. The Wimperis Course Setting Bomb Sight (above right, at left) is perhaps the best known and most used bombsight of this type. Versions of this bombsight were used by many air forces, and especially the Royal Air Force, through World War II.

Robert V. Gates, a retired Navy Senior Executive, served as the Technical Director at the Naval Surface Warfare Center (NSWC), Indian Head Division and in many technical and executive positions at NSWC, Dahlgren Division. He holds a B.S. in Physics from the Virginia Military Institute, a Master's in Engineering Science from Penn State, a Master's and PhD in Public Administration from Virginia Tech. and is a graduate of the U.S. Naval War College. Dr. Gates is the Vice President of the board of the Dahlgren Heritage Foundation, President of the Educational Foundation Board of Rappahannock Community College, and a former adjunct professor at the Naval War College and the University of Mary Washington. He has previously been published in the International Journal of Naval History*, the Naval Institute* Proceedings*, the Marine Corps* Gazette*, and the Eighth Air Force Historical Society magazine. He has also presented papers at two McMullen Naval History Symposia.*

Developments in the Interwar Period

Many in the Army considered that the role of aircraft, including bombers, was support for ground forces. Hence, the emphasis was on operating at low altitude. The U.S.



Wimperis Mark 1A CSBS. ***(RAF Museum Photo.)***

Bombing of ***Ostfriesland. (Naval History and Heritage Command photo.)***

Navy considered ships to be the primary targets of its bombardment missions. In its search for an effective means of accomplishing this mission it considered level bombing, dive bombing, glide bombing, and aerial torpedo attack. Many senior officers in both services continued to believe that aircraft would have little utility in future wars. There were, however, other officers who felt differently and developments in aircraft technology continued.

The Air Corps Tactical School (ACTS) at Langley Field, Virginia (and later Maxwell Field, Alabama) was taking a different look at the bombing mission. While some held that the mission required bombing the civilian population, the view that prevailed was that the proper target was the enemy's economic infrastructure. Destroying such targets given the damage radius of the available bombs and with minimal collateral damage required a higher level of accuracy than was then achievable. A review of expected advances in air defense by the Army also indicated that bombers were going to be required to operate at significantly higher altitudes. Again, existing bombsights weren't up to the challenge. They were designed to operate at low altitudes and accuracy grew significantly worse as bombing altitude increased.

In June and July of 1921, Army and Navy pilots dropped bombs on a variety of targets including the anchored German battleship *Ostfriesland* (right above). The Navy pilots dropped bombs from an altitude of less than 2500 feet and achieved hits with only nineteen percent of them. Brig. Gen. Mitchell's Army pilots did somewhat better—30 percent of their bombs hit the *Ostfriesland*—using a Wimperis Course Setting Bomb Sight.

A 1924 report for the Secretary of the Navy concluded that "it is absurd to think that either the aerial bomb or the submarine torpedo have furnished the effectual answer to the capital ship." The Army came to the same conclusion.

The Army Bomb Board had previously (in 1919) identified bombsight stability (resulting from aircraft movement) as a primary source of inaccuracy and gyro–stabilization of the bombsight as a solution. As a result, the Army attempted to improve the two standard bombsights—the Army Mark 1-A and the Navy Mark III Wimperis bombsights. They worked with several designers and the Sperry Gyroscope Company to develop bombsights that would meet both their low and high altitude requirements. For the next decade the Army evaluated a number of low altitude and high altitude, synchronous bombsights. Each, in turn, was found to be unsatisfactory because of performance or weight and size. The effort culminated with a series of tests in 1931. That summer, the army tested two of their bombsights and the Navy's Norden Mark XI at Langley Field and March Field, California to drop 108 bombs from different altitudes. The results showed that the Norden bombsight performed the best although it was the most difficult to use.

The Navy tested a production model Mark XI and a developmental prototype of the Mark XV against the anchored USS *Pittsburgh* in early October of that year. They achieved three hits out of fourteen bombs dropped using the Mark XI and four out of eight with the Mark XV.[1] This was apparently the first time that the Army became aware of the Mark XV. They stopped their bombsight development program and began efforts to acquire technical specifications of the Mark XV in order to produce their own version. In the end, they agreed to allow the Navy to procure bombsights for both services.

Norden and the Navy

The Navy's Bureau of Ordnance (BuOrd) had the responsibility for developing bombsights for the Navy and in January 1920 contracted with Carl L. Norden (next page) to improve the Navy Mark III bombsight, a modified Wimperis device.

Norden immigrated to the United States in 1904 and worked for Elmer Sperry for two years developing ship gyrostabilizers. Their relationship was a rocky one—Sperry

Carl L. Norden. ***(US Navy Photo.)***

disliked Norden's appetite for "vile black cigars" and Norden resented Sperry's proposal that Norden sign over his future gyrostabilizer patents to the Sperry Gyroscope Company. They parted ways in 1913 although they worked together on various projects during World War I.

When the Navy wanted to add gyro stabilization to the Mark III bombsight, they turned to Norden. His first efforts included adding gyro-stabilization to the bombsight along with a telescope to better sight the target and a means for providing flight directions to the pilot. When the results of his first effort were unsatisfactory, Norden used Navy funding for three pilot direction indicators (PDI) for the Mark III bombsight and family funds to continue work on a better bombsight. In June 1922, impressed with his progress, the Navy contracted with him for three experimental bombsights designated the Mark XI.

A year later the Navy was concerned that the project was too big for one man, especially the man they knew as "Old Man Dynamite" because he was so difficult to work with due to his generally unsociable and reclusive nature. They sent him a collaborator, Theodore Barth. Barth brought production engineering, business acumen and political skill—traits that Norden lacked—to the partnership. This successful relationship lasted until both men retired after World War II.

Norden worked out of his home in Zurich and Barth's apartment in New York City, and, using the equipment and skilled labor of the Witteman-Lewis Aircraft Company, delivered the three PDIs and three experimental Mark XI bombsights—all handmade—to the Navy in the winter of 1923 and spring of 1924. Bench and flight testing of the Mark XI was conducted at the U.S. Naval Proving Ground in Dahlgren, Virginia in 1924. Neither Norden nor the Navy was pleased with the performance of the bombsights as test bombs fell with "alarming irregularity." The Navy also believed that the sight was too complicated.

Many changes were identified during the initial testing and BuOrd contracted with Norden for modifications to two of the Mark XI bombsights. The modified bombsights were delivered to Dahlgren for flight testing in 1925. Tests during the summer and fall of 1925 showed that the changes were worthwhile. The eighteen bombs that were dropped from an altitude of 3000 feet in the final test achieved a mean impact point that was nine feet short in range but 187 feet to the right of the flight path.

The Navy test bombardier was impressed but reported that the sight was too complex and required "both hands, both feet, and the teeth" to operate. In an open cockpit, the wind and cold made fine adjustments to the sight nearly impossible. Norden viewed the basic design as good and the problems correctable.

The Navy completed testing of the Mark XI in October 1927 and, despite continuing problems with leveling, vibration, and the PDI, began negotiations with Norden and Barth for the purchase of eight Mark XI bombsights and PDIs. Norden and Barth balked at the proposal because they considered themselves consulting engineers not production contractors. In 1928, after additional encouragement from the Navy and some unwritten agreements, Norden and Barth agreed to form Carl L. Norden, Incorporated and to produce and deliver eighty Mark XI sights with spare parts and toolkits for $384,000. They also agreed to transfer all patents, models, and designs to the government two years later. Norden said he was paid $1 for these rights although Navy records show he was paid $250. A very low price in either case.

Bureau of Ordnance testing related to the development of the Mark XI bombsight at the Naval Proving Ground in Dahlgren, Virginia began in 1922. In the five-and-a-half-year period leading up to the production contract, Norden and Barth visited Dahlgren fifty-one times. The bench and flight testing at Dahlgren are credited with uncovering numerous design and performance issues. Dahlgren was also the site of the first school to teach mechanics how to maintain the Mark XI bombsight.

Production of the Mark XI began slowly and Norden and the Navy tested and improved each sight as it was produced. Norden shipped the first three Mark XI bombsights to Dahlgren for testing in early 1929. The bombsights were essentially handmade and production continued at three units per month. Eighty-three Mark XI bombsights were procured under the first production contract.[2] One was sent to the Army at Wright Field, Ohio for testing and the rest were tested at Dahlgren. With all of its shortcomings and complexity, the Mark XI represented a significant improvement over other bombsights. However, it did not resolve the limitations of high altitude horizontal bombing.

After signing the contract with the Navy Norden went to his mother's Zurich home to work on his next design, the Mark XV. This was the bombsight (known as the M-series by the Army Air Force) that was eventually used by both the Army and the Navy during World War II. Two prototypes of the Mark XV, a timing sight and a synchronous sight, were delivered to Dahlgren in February 1931, for evaluation. While timing sights were the current technology, all developers knew that synchronous sights held more promise for accuracy. Both the Army and the Navy supported the development of such bombsights.

A timing sight uses a telescope and a timer to measure the movement of a point on the ground relative to the aircraft. The time and aircraft altitude are used with a ballistics table to determine the angle at which the telescope should be set. If the pilot keeps the aircraft at the same altitude and speed, then the bombs should be released when the target appears in the telescope. Variations in aircraft altitude and speed, as well as wind, are the major causes of inaccuracy. The Mark XI was perhaps the best of the timing bombsights.

In synchronous bombsights, the bombardier adjusts the speed of a wheel or gear in the bombsight mechanism to match the movement of the aircraft over a point on the ground. This synchronized the bombsight with the aircraft's ground speed. Norden described his Mark XV sight as being able to provide ground speed, angles of drift, and true air speed. It could also hold a true compass course and compensate for earth rotation.

The timing method required a long bombing run at a fixed speed and altitude. Conversely, the synchronous sight precluded a long bombing run since ground speed was computed as an instantaneous rate. Navy bombardiers at Dahlgren found that they could adjust the Mark XV sight in six seconds compared to fifty seconds for the Mark XI.

Testing at Dahlgren was intended to identify deficiencies in a new concept, not as acceptance tests. For this reason, the Naval Proving Ground conducted bench tests of the components of the sight as well as intensive flight testing. Dahlgren provided a final report to BuOrd containing 33 pages of deficiencies and suggested corrective actions. Flight tests showed that the Mark XV was twice as accurate as the Mark XI (i.e., the percentage of hits was twice as high). Testing ended in August 1931 when BuOrd issued a production contract for the Mark XV bombsight.

The Mark XV was given more tests than any other sight ever developed by BuOrd. Life tests of various components and analytical studies continued into 1932. On April 18, 1932 the first order for the new sight was placed—thirty-two for the Navy and twenty-three for the Army. The Navy received its first production unit in September 1932 and the Army received its in April 1933. The sights continued to be nearly handmade and every unit went to Dahlgren for calibration and acceptance testing.

The Naval Proving Ground received Norden's next improvement—the Stabilized Bombing Approach Equipment (SBAE)—in February 1935. The Navy tested the SBAE at Dahlgren from 1935 until the delivery of the first production unit in 1937. It was believed by both the Navy and the Army that a remaining source of error was the transfer of flight instructions from the bombardier to the pilot and the resulting piloting errors during the bombing run. Norden developed the SBAE, an automatic flight control system to transfer adjustments of the bombsight's controls through mechanical linkages to the azimuth gyro which allowed the bombardier to fly the aircraft in roll and yaw. Testing revealed both the strengths and weaknesses of the prototype. Flight tests showed a thirty percent improvement in Mark XV accuracy in smooth air and thirty-nine percent improvement in rough air. The first production models were available in late 1936 and production began in June 1937 at the rate of seven to ten per month.

The Army Air Corps had long worked with the Sperry Corporation to equip its aircraft with autopilots and attempted to connect the Norden bombsight and the Sperry A-2 autopilot—without success. In the end, the Army needed both the Sperry autopilot (for aircraft control) and the SBAE. Carl Norden argued that it was a duplication of effort for the Army to equip its aircraft with both Sperry autopilots and Norden SBAEs. In addition to continuing to compete with Sperry, he also preferred to work with the Navy rather than the Army. (He once told an Army Colonel "No man can serve the Lord and the Devil at the same time—and I work for the Navy.")

Tests at Dahlgren compared the Norden SBAE with the Sperry autopilot and concluded that the SBAE "… is at least the equal of if not superior to the Sperry gyro-pilot." The Air Corps did not want to equip their bombers with both the SBAE and the Sperry autopilot and continued to pursue an SBAE replacement. In response, the Navy developed an adapter that allowed the Norden bombsight to be connected to the Sperry A-3 autopilot. Dahlgren completed tests of the adapter in August 1941 and forty units were produced between September and December.

The Army Air Force asked Minneapolis-Honeywell Regulator to develop new automatic flight control equipment (AFCE[3]) with electronic parts to link the A-3 autopilot and the Norden bombsight without the Navy's adapter. This system (designated the C-1), ordered into production in October 1941, was the standard autopilot/AFCE/SBAE for the remainder of World War II.

Procurement became a major headache because the Navy refused to share production with the Army. In addition, because the bombsights were essentially handmade between 1932 and 1938, the Norden Company produced only 121 bombsights per year. The Navy had agreed to share production with the Army but the Navy and Norden never developed a production schedule. The Navy filled its requirements—even as it moved away from horizontal bombing—before sending any bombsights to the Army.

The Army reacted by restarting the acquisition of Sperry S-1 bombsights, which they had stopped in the 1930s. The object was to bring pressure on Norden and the Navy to meet Army needs. The Army authorized Sperry to produce 5000 S-1 bombsights in 1941. After testing and training, the Army decided that the S-1/AFCE combination was inferior to the Norden Mark XV and production was halted in 1943. In the end, 5,563 S-1 bombsights were procured by the Army (compared to 81,537 Norden bombsights[4]) and most were installed in B-24s. Even after Norden added additional production sources to meet Army Air Force needs, shortages of materials, specialized machine tools, and skilled labor kept production below required levels. There was a major shortage of bombsights that extended to late 1943.

All Norden bombsights continued to go to Dahlgren for bench and flight testing. After a period of shop testing, bombsights were sent for flight testing. Typically, each sight was used to drop six to eight bombs. Approximately half were dropped on each of two opposite courses. Bomb impact data were collected and mean impact points and mean deviations (both in range and deflection) were calculated. Finally, the Aviation Officer reviewed the data and either accepted or rejected the sight. Rejected sights were sent back for additional shop and flight testing. It was estimated that this process delayed delivery for four to five weeks.

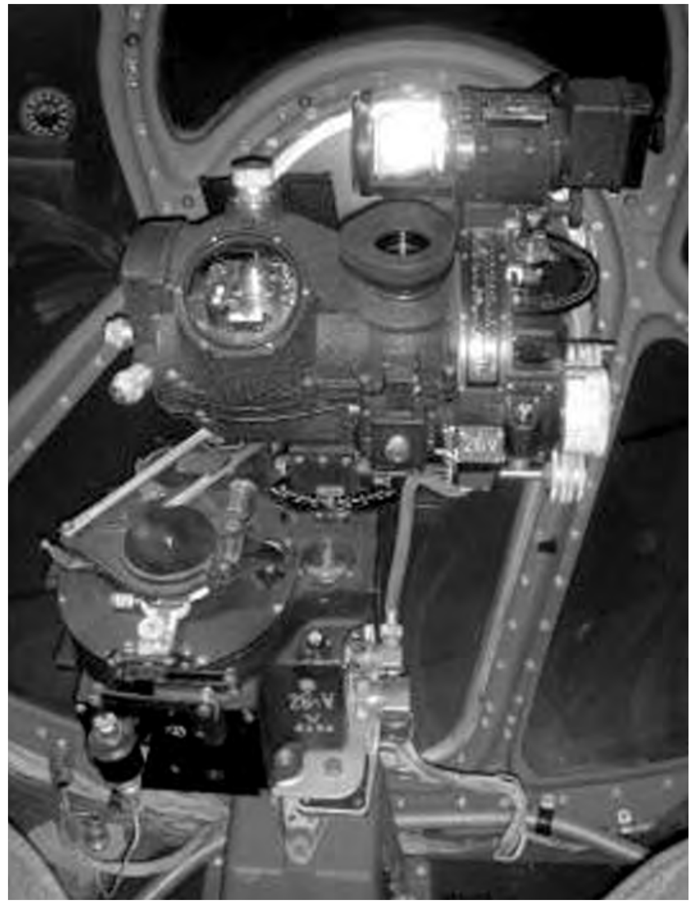
Even though Dahlgren testing was impeding bombsight availability, BuOrd refused to eliminate the testing. They did make some concessions—only one bombsight of every ten produced would be sent to Dahlgren for testing. They also agreed that bench testing would be completed on the day that the sight was received. Further, Dahlgren would only flight test the number of sights that could be completed within fifteen days of bench testing.[5]

The number of Mark XV bombsights that underwent acceptance testing at Dahlgren each year are given in the following table[6]:

Year	Number Tested
1932	52
1933	41
1934	104
1935	92
1936	122
1937	181
1938	85
1939	187
1940	473
1941	876
1942	610
1943	1494
1944	2316
1945	873

Note that lot acceptance testing started during 1942 and only 10 percent of the bombsights were delivered to Dahlgren thereafter. A total of 4,938 bombsights were delivered to the services in 1942. The totals given for the remaining years are 10 percent of total production.

As the war went on, it became clear that Army Air Force performance requirements exceeded those of the Navy and that the Navy had little interest in modifying the sight since it had chosen dive bombing as its preferred means of attacking moving targets. Thus, improvements to the bombsight were motivated by the Army and, by late in the war, were being developed by someone other than the Norden Company.



Norden Mark XV Bombsight with C-2 Stabilizer. ***(Twinbeech.com photo.)***

Between 1932 and the end of World War II, nearly 90,000 Mark XV (or M-9) bombsights—81,537 for the Army Air Force and 8,353 for the Navy—were produced at a total cost of $1.1 billion. Production began to catch up with demand by late 1943, but mass production techniques also led to declining quality. The Norden Company was not interested in helping to solve the problem and in late 1944, seventy-five to eighty percent of all sights produced failed to meet specifications.

Operational Accuracy

The accuracy achieved at Dahlgren during testing was never duplicated in combat. The Navy specification was for two and a half mils (or two and a half feet mean miss for every 1,000 feet of altitude). The inherent accuracy of the 1944 Norden sights was fourteen mils, due to looser manufacturing tolerances. By some reports, the accuracy achieved in combat was more than fifty mils.

The standard measure of bombing accuracy was the statistical parameter Circular Error Probable (CEP), the radius of a circle, centered on the target, within which fifty percent of the bombs would fall. This proved impossible to visually quantify for the large missions over Europe in World War II. CEP was replaced by the number of bombs that fell within a 1,000 foot circle. This was calculated by drawing a circle with a 1,000 foot radius (on a post attack photograph) around the greatest concentration of bombs.

The distance from the target point to the center of the circle was the circular error and the measure was the percentage of bombs that fell within this circle.

There were several problems that contributed to the reduced accuracy under combat conditions. The first is inherent to the sight itself. Norden bombsights were optical sights and the bombardier had to be able to see the target. That would be nearly impossible for all but the first few groups over the target due to smoke and dust generated by the bombing. Data gathered in 1943 show that an average of 13.6 percent of bombs dropped by the first three groups fell within 1,000 feet of the target while the average dropped to five percent for the last groups.[7] Cloud cover over the target had the same effect. European weather data from 1942 show that there were only 113 days when conditions over the target were acceptable for visual bombing.[8] Data from January 1944 through March 1945 are similar—there were 132 visual bombing days in Northern Europe.[9] In general, miss distances at least doubled when targets were obscured.

The limitations of an optical bombsight were well known to the Army and they had started working on the problem as early as 1939. They tried a variety of options, including beacon and radio direction, but settled on radar aiding of the bombsight. The most used system was the H_2X (or "Mickey") radar. It replaced the optical telescope and allowed the operator to pass angle measurements to the bombardier so that he could align the sight to the unseen target. The bombardier would drop the bombs based on the radar although he could override the radar if the target was visible. This system was inherently inaccurate. Operator error, beam width, and target spot size all contributed to error. Thirty percent of bombs fell within 1,000 feet with visual bombing in clear weather while zero to five percent of bombs fell within 1,000 feet with H2X or H2X-aided visual bombing.

Another significant factor was altitude since error increased with altitude. Most testing (and training) was done below 10,000 feet altitude. The average bombing altitude in Europe through the end of 1944 was 24,500 feet. The improvement in accuracy obtained in 1945 was largely due to a reduction of average bombing altitude to 16,000 feet because air supremacy had been achieved.

The human factor also contributed to inaccuracy. Bombardiers at Dahlgren were, in general, better trained and more experienced. Perhaps more important was the fact that they were operating in benign conditions. Errors in determining and maintaining altitude, speed, or angular orientation in combat contributed to inaccuracy.

Army Air Force tactics also contributed to inaccuracy. While protection of the bombers forced them to fly and bomb from higher altitudes, it also required them to fly in large formations. As a result of these large formations, bombardiers could not drop bombs individually. The standard tactic by early 1944 was for a formation to have a lead bombardier (and deputy lead bombardiers) who would use his bombsight while all others dropped their bombs on his signal. Weather also drove changes in tactics. Precision bombing was only possible on clear days. On other days, bombing of area targets was dictated by H2X accuracy. Accuracy increased in late 1944 and 1945 due to bombing from lower altitudes.

Another factor was target selection. Given the small size of the high explosive bombs typically dropped (250 or 500 pounds) and the relative lack of bombing accuracy, the aim point was usually the center of the target system or city. This was done, in part, to ensure that the greatest amount of damage was done to the target system. Unfortunately, the critical areas of the target system or city were seldom in the center. That, coupled with the small damage radius of the individual bombs, usually resulted in damage to buildings but not always to the equipment in the building. The typical result was a temporary reduction in production. Synthetic oil targets were easy to locate visually and highly concentrated which lent themselves to accurate visual bombing. The greatest damage—often permanent—was done at the end of the war with 2,000—4,000 pound bombs.

While some used the discrepancy between design and operational accuracy to question the effectiveness of high altitude bombing, the performance of the Eighth Air Force in Europe refutes this. In the end, seven and a half million bombs were dropped from an average altitude of 21,000 feet with 31.8 percent of them falling within 1,000 feet of the aiming point. While strategic bombing and the Norden bombsight did not meet prewar expectations for precision, German oil production was stopped and twenty percent of German war production was destroyed in the last sixteen months of the conflict.

Epilogue

The Norden bombsight continued to be used into the 1950s. Bombsights on older aircraft were left in their wartime state and used when the aircraft were deployed during the Korean War. Mechanical bombsights were made obsolete by technology and radar bombsights began to replace them during the 1950s. While contemporary radar bombsights were less accurate than the Norden, precision bombing was not important with nuclear weapons. In addition, mechanical bombsights, like the Norden, operated too slowly for the newer, faster bombers.

Over the years, more advanced radar bombsights were developed and, later, electro-optical systems such as laser and infrared target designators and GPS satellite systems eliminated the need for bombsights altogether.

The last recorded use of a Norden Mark XV bombsight was in Vietnam. It was installed in the P2V aircraft of Naval Air Observation Squadron Sixty-Seven (VO-67). The bombsights were used in *Operation Igloo* White for implanting Air-Delivered Seismic Intrusion Detectors (ADSID) along the Ho Chi Minh Trail in 1968.

The Norden bombsight represented a major step forward in bombsight technology and was a prerequisite for the implementation of Army Air Force strategy in World War II. Even though it didn't live up to its reputation for "pickle barrel" accuracy, it made an important contribution to victory in World War II. Its position in popular history is also secure.

The Navy's role in the development of the Norden bombsight is less well known than is its use by the Army Air Force in World War II. Even less known is the role that the Naval Proving Ground in Dahlgren, Virginia played in the development, testing, and acceptance of the Norden bombsights beginning soon after World War I. It's clear that all deserve credit for their significant contributions to the breakthrough capability represented by the Norden bombsight. ■

REFERENCES

Biddle, Tami Davis. *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas about Strategic Bombing, 1914-1945.* Princeton, NJ: Princeton University Press, 2002.

Brodie, Bernard, *Sea Power in the Machine Age*. Princeton, NJ: Princeton University Press, 1941.

DuBuque, Jean H. and Robert F. Gleckner. *The Development of the Heavy Bomber, 1918 - 1944*. Maxwell AFB, Ala.: Air University Press, 1951.

______, *Strategy in the Missile Age*. Princeton, NJ: Princeton University Press, 1959.

Finney, Robert T. *History of the Air Corps Tactical School*. Air Force History and Museums Program, 1998.

Hamilton-Patterson, James. *Marked for Death: The First World War in the Air*. New York: Pegasus Books, 2016.

Haun, Phil., Ed. *Lectures of the Air Corps Tactical School and American Strategic Bombing in World War II*. Lexington, KY: University Press of Kentucky, 2019.

Hedrick, Captain David I., USN. "U.S. Naval Proving Ground, Dahlgren, Virginia: History, April 1918—December 1945 (NPG-H-1)." Dahlgren, VA: NPG, 1945.

Holley, I.B, Jr. *Ideas and Weapons*. New Haven, CT: Yale University Press, 1953.

Hurley, Alfred F. *Billy Mitchell: Crusader for Air Power*. Bloomington: Indiana University Press, 1975.

Jones, Arthur L. "Test of Mark 17 Bombsight (Experimental Department Memorandum No. 1007-44)." Dahlgren, VA: NPG, 1944.

Kruskal, William. "Precision of Present Method of Testing Mark 15 Bombsights (Experimental Department Memorandum No. 1012-43)." Dahlgren, VA: NPG, 1944.

Kruskal, William and D.W. Stoner. "Tests of the Mark 17 Bombsight (Norden Aiming Angle or Dive Sight) (Experimental Department Memorandum No. 1034-44)." Dahlgren, VA: NPG, 1944.

Leith, Charles H. "Our First Bomber: Charles Candy Middlebrook, Esq. "Middy" (1896-1965) and his part in the Norden Bombsight of W.W. II." Fredericksburg, VA: Self Published, 1987.

McCollum, Kenneth G., Ed. *Dahlgren*. Dahlgren, VA: NSWC, 1977.

McFarland, Stephen L. *America's Pursuit of Precision Bombing, 1910—1945*. Washington, D.C.: Smithsonian Institution, 1995.

Mets, David R. *Master of Airpower: General Carl A. Spaatz*. Novato, CA: Presidio Press, 1988.

Morris, Craig F. *The Origins of American Strategic Bombing Theory*. Annapolis, MD: Naval Institute Press, 2017.

Murray, Williamson and Allan R. Millett (Eds.). *Military Innovation in the Interwar Period*. Cambridge: Cambridge University Press, 1996.

Overy, Richard. *The Bombers and the Bombed: Allied Air War Over Europe, 1940 - 1945.* New York: Viking, 2013.

Rowland, Buford and William B. Boyd. *U.S. Navy Bureau of Ordnance in World War II*. Washington, D.C.: Government Printing Office, 1953.

Saward, Dudley. *Bomber Harris: The Story of Sir Arthur Harris*. Garden City, NY: Doubleday & Company, 1984.

Searle, Loyd. "The Bombsight War: Norden vs. Sperry." *IEEE Spectrum* (September 1989, 60-64.

Tate, James P. *The Army and Its Air Corps: Army Policy Toward Aviation, 1918 - 1941*. Maxwell AFB, AL: Air University Press, 1998.

Tremblay, Michael. "Deconstructing the Myth of the Norden Bombsight" master's thesis, University of Victoria, 2009.

NOTES

1. McFarland, p.72.
2. Hedrick, p. 240.
3. The Army called this equipment "AFCE" because the Navy classified the term "Stabilized Bombing Approach Equipment (SBAE)."
4. McFarland, p. 148.
5. There were critics of flight testing at NPG. They felt that flight testing provided an inadequate measure of acceptability. However, they conceded that flight testing was required in order to discover if there were conditions that cause errors that wouldn't be revealed by ground testing.
6. Hedrick, p. 240.
7. Overy, p. 157.
8. Overy, p. 155.
9. McFarland, p. 178.